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NEW HYBRID WASTEWATER TREATMENT SYSTEM USING ANAEROBIC MICROORGANISMS AND REED *(Phragmites communis)*

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APPROVAL

NEW HYBRID WASTEWATER TREATMENT SYSTEMS USING ANAEROBIC MICROORGANISMS AND REEDS

Phragmites communis

By B. C. Wolverton

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense of Energy Research and Development Administration programs has been made by the NSTL Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

Mark A. Payne
Manager, Installation Operations

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16. ABSTRACT

A small hybrid wastewater treatment system consisting of a settling tank in series with an anaerobic filter-reed *(Phragmites communis)* treatment cell was evaluated and compared with a similar plant-free system. Data demonstrated that by combining anaerobic filters, also referred to as attached film filters, and vascular aquatic plants a synergistic effect is produced which increases the treatment efficiency of each individual system. The plant-free system reduced the BOD_5 from 114 to 31 mg/l in 6 hours as compared to a reduction of 110 to 9 mg/l in the anaerobic filter-reed system in the same length of time. The BOD_5 and TSS after 24 hours in each component of the plant-free system was reduced from 114 to 14 mg/l and 51 to 15 mg/l, respectively. Under the same conditions, the hybrid system reduced the BOD_5 from 110 to 3 mg/l and the TSS from 68 to 6 mg/l. The hybrid system also reduced the total kjeldahl nitrogen (TKN) from 16.1 to 2.9 mg/l, total phosphorus (TP) from 4.4 to 2.0 mg/l, and the ammonia (NH_3-N) from 12.4 to 0.6 mg/l after 24 hours of exposure while the plant-free system demonstrated insignificant reduction of these components.

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INTRODUCTION

The most important recent wastewater regulation by the United States Environmental Protection Agency (EPA) requires secondary treatment as the minimum acceptable level of treatment prior to surface water discharge. This, combined with increased industrial waste discharged into domestic sewers, has increased significantly the need for improved wastewater treatment methods to meet the secondary standards as well as the removal of hazardous chemicals in many areas.

In many locations where the available supply of fresh groundwater has become contaminated with toxic chemicals or inadequate rainfall has drastically lowered the groundwater table, advanced wastewater treatment and reuse of wastewater will be a necessity in the near future.

Because of these increasing demands to improve wastewater treatment methods, innovative wastewater treatment technology must be developed. The present economic conditions in the United States also dictate that this technology must be less energy intense, cost effective and more efficient than present wastewater treatment methods.

The separate uses of anaerobic microorganisms and vascular aquatic plants have been evaluated during the past 10 years and show promise as alternate wastewater treatment methods. The water hyacinth *(Eichhornia crassipes)* in wastewater treatment has been researched and studied extensively both in the laboratory and field applications (1, 2, 5, 6, 20, 23, 25, 28, 30, 31, 38). This plant has been successfully used in wastewater treatment in the south and southwestern United States (4, 35, 37).

The anaerobic filter concept for treating domestic wastewater was demonstrated by Young and McCarty in 1969 (39). Since that time the development of this technology for both energy production and wastewater treatment has developed rapidly (16, 32, 36).

Research conducted at NASA's National Space Technology Laboratories (NSTL) in Mississippi during the past several years has led to the development of a simplified natural biological process which promises to be a major technological contribution to wastewater treatment and water recycling. This process is made up of a combination of the oldest of wastewater treatment technology (septic tanks and trickling filters) and the latest development in anaerobic filter and vascular aquatic plant wastewater treatment technology.

Data from this new hybrid system using the common reed and rock filters are presented in this paper.

CHARACTERISTICS OF THE COMMON REED *Phragmites communis*

The common reed is a tall aquatic plant which can grow up to 4 m with an extensive rhizome system. The leaf blades are deciduous and flat, 1-5 cm wide and 2-6 cm long, tapering to long slender points. The plant spreads by means of the horizontal rhizomes. Both horizontal and vertical rhizomes develop with the vertical rhizome developing buds which form the aerial shoots. The reeds grow in a wide range of water quality conditions. They are found in peat bogs where the pH varies from 2.8 to 6.0 and in saline lakes where the pH is 8.0-8.5. Reeds are salt resistant plants, preferring salinities below 10 ppt but growing in habitats with fluctuating salinities occasionally reaching 40 ppt (12, 15, 22, 24).

The common reed whose ability to purify wastewater has been well established (3, 27) grows throughout the world and is the most widespread of the emergent aquatic plants (26). Although essentially a temperate plant of both hemispheres, it is found from the tropics to the Arctic Circle. Aerial shoots develop only in warm weather, but the extensive underground system of rhizomes continue to grow horizontally during cold periods which should allow for the wastewater treatment process to continue during cold months.

Reeds have the ability to absorb nitrogen, phosphorus, other nutrients and heavy metals directly from water by means of finely divided roots which develop at nodes submersed below the water level (7).

The nitrogen removal potential of reeds is 330-800 kg/ha for above ground mass (7, 10, 18, 21, 22, 40) and 350-830 kg/ha for below ground plant mass (3, 11, 19). The ability of reeds to develop aquatic roots and absorb nutrients and other elements directly from water is advantageous, especially in nutrient-poor soils and is an important factor in using this plant for wastewater treatment applications.

The phosphorus removal potential of reeds is 10-80 kg/ha for above ground plant mass and 38-74 kg/ha for below ground plant mass. Reeds are salt-resistant plants, and seldom take up sodium. The sodium removal potential of the common reed is 4.6-49.3 kg/ha (7, 10, 18, 19, 22, 27, 29).

Reeds have an inherently high transpiration rate but a low unit mass of leaves moderates the overall transpiration rate of reed beds. In Poland the transpiration of *Phragmites communis* has been measured as 30-100 cm/yr (17, 33).

Biomass production reported for reeds in the U.S. ranges from 6,540 to 39,990 kg/ha (34). Combined above ground and below ground production in hydroponic culture ranges from 8,230 to 74,010 kg/ha/yr in 1- to 3-year old cultures (8, 9).

DESCRIPTION OF EXPERIMENTAL SYSTEMS

The experimental systems shown in Figure 1 consisted of plastic covered containers with 113-liter capacities, which were used as anaerobic settling tanks for receiving raw sewage. In each experiement, 87 liters of raw sewage was collected in the settling tanks. After the raw sewage settled 24 hours, it was pumped into metal troughs, 50.5 cm wide, 30.5 cm deep and 298 cm long, filled to 16 cm with 2.5-7.5 cm diameter railroad rocks with a top layer, 5 cm deep, of 0.25-1.3 cm diameter pea gravel. One trough was free of plants and another trough contained reeds *(Phragmites communis)* which were grown on the surface of the rock filter. The wastewater retention time in the trough was 24 hours.

SAMPLING AND ANALYSIS

Raw sewage was obtained from NSTL Sewage Lagoon #1 influent for all experiments. The raw sewage was pumped directly into the settling tanks and transported back to the laboratory. Initial samples were removed from the settling tank at the laboratory. The delay of approximately 30 minutes prior to sample collection for analysis caused the initial data to be low. Analyses were performed according to <u>Standard Methods</u> (41). The 5-day biochemical oxygen demand (BOD_5) was determined on all samples. Total suspended solids (TSS) were determined on all samples except those after 6 hours in the anaerobic filter. Total kjeldahl nitrogen (TKN), ammonia-nitrogen (NH_3-N), and total phosphorus (TP) were determined on initial and final samples.

The initial and final liquid volumes were measured to calculate evaporation and evapotranspiration rates from the plant-free filter and the rock-reed filter, respectively. Minimum and maximum daily greenhouse temperatures averaged 19°C and 35°C, respectively.

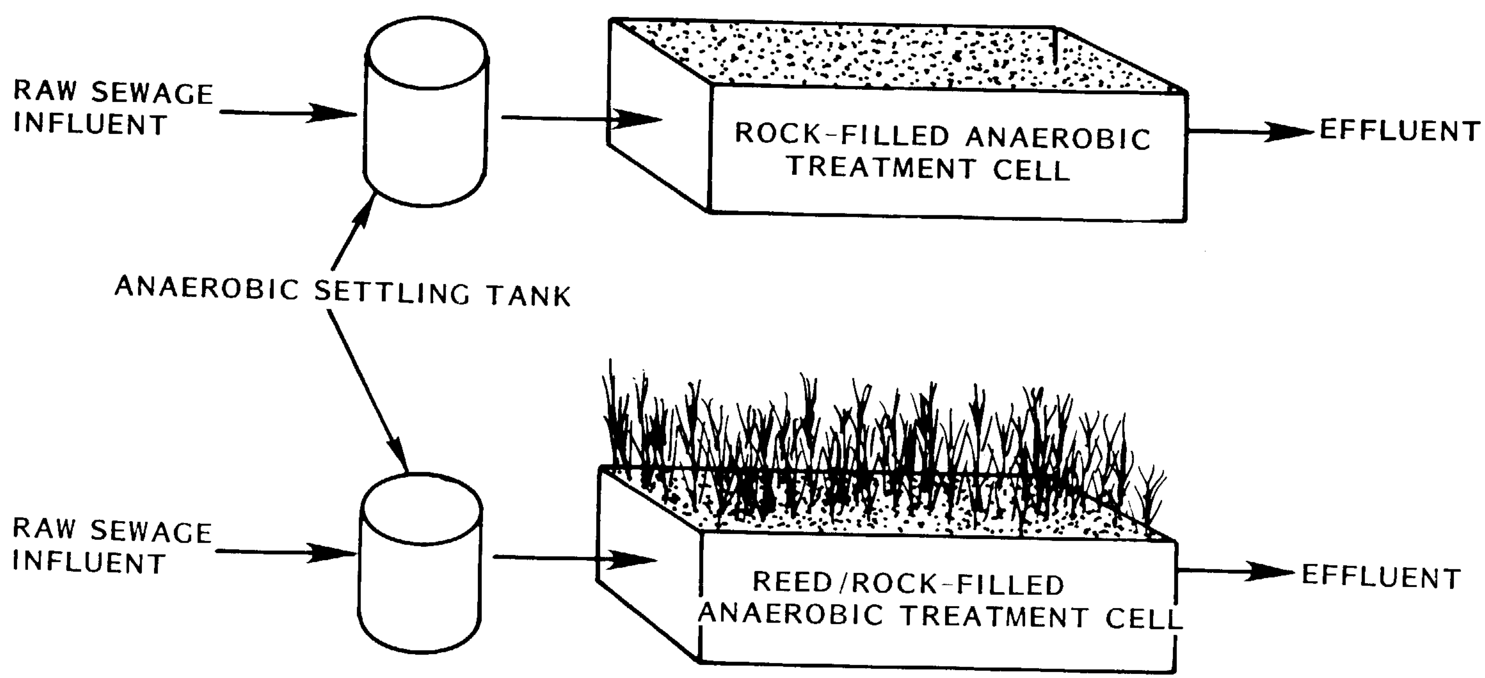

Figure 1. Experimental wastewater treatment systems using anaerobic microorganisms and reeds *Phragmites communis*.

RESULTS

The raw data for BOD_5 and TSS of the plant-free anaerobic filter system is presented in Table 1. The average of the ten experiments performed demonstrated that a plain anaerobic filter in series with a settling tank can reduce the BOD_5 from 114 to 14 mg/l and the TSS from 51 to 15 mg/l in a total of 48 hours. The primary settling tank is effective for TSS removal for secondary treatment. However a BOD_5 of 81 mg/l still far exceeds the 30 mg/l EPA maximum discharge requirements. The anaerobic filter was far more efficient for BOD_5 removal due to the increased surface area for microbial growth.

The hybrid system was the same as the previous system except for the addition of reeds to the anaerobic filter. The settling tank for this system showed approximately the same efficiency for BOD_5 and TSS removal as the one for the plant-free system as seen in Table 2. The hybrid anaerobic system reduced the BOD_5 from 110 to 3 mg/l and the TSS from 68 to 6 mg/l in a total of 48 hours. However, a 24-hour retention time is not needed with the hybrid system. A 6-hour sampling of this filter showed that the BOD_5 had already been reduced to 9 mg/l, and all the data were well under the 30 mg/l maximum. A direct comparison of the average BOD_5 and TSS of both systems can be seen in Figures 2 and 3, respectively.

The hybrid system was also superior for nutrient removal. The plant-free system data shown in Table 3 show that this system reduced the TKN from 15.4 to 13.6 mg/l, the NH_3-N from 12.6 to 11.6 mg/l, and the TP from 5.8 to 5.3 mg/l after 24 hours in each component. The average data are presented in bar graph form in Figure 4. The hybrid system with reeds reduced the TKN from 16.1 to 2.9 mg/l, the NH_3-N from 12.4 to 0.6 mg/l, and the TP from 4.4 to 2.0 mg/l as shown in Table 4. The mean data are presented in

Table 1. BOD_5 data for initial raw sewage treated for 24 hours in an anaerobic settling tank (Step 1), followed by 6 (Step 2) and 24 (Step 3) hours in a rock filter free of reeds.

	BOD_5, mg/l				TSS, mg/l		
Exp. #	Initial	1	2	3	Initial	1	3
1.	55	63	32	17	68	38	26
2.	94	59	33	2	32	14	16
3.	111	89	---	9	16	23	15
4.	124	113	66	10	56	35	9
5.	117	42	18	16	43	38	---
6.	119	99	25	21	43	34	9
7.	134	109	35	16	74	32	26
8.	135	123	26	15	62	21	21
9.	119	51	31	9	66	14	5
10.	133	60	15	21	48	20	8
Avg.	114	81	31	14	51	27	15

Table 2. BOD_5 data for initial raw sewage treated for 24 hours in an anaerobic settling tank (Step 1), followed by 6 (Step 2) and 24 (Step 3) hours in a rock-reed filter.

	BOD_5, mg/l				TSS, mg/l		
Exp. #	Initial	1	2	3	Initial	1	3
1.	152	119	21	7	113	76	---
2.	52	48	4	6	---	---	8
3.	96	70	10	2	129	59	---
4.	141	97	10	1	---	---	5
5.	67	50	4	1	51	22	1
6.	79	64	10	3	41	35	1
7.	134	46	3	5	74	24	14
8.	127	79	17	1	57	22	10
9.	120	74	9	1	43	26	6
10.	131	70	1	1	39	24	2
Avg.	110	72	9.0	3.0	68	36	6.0

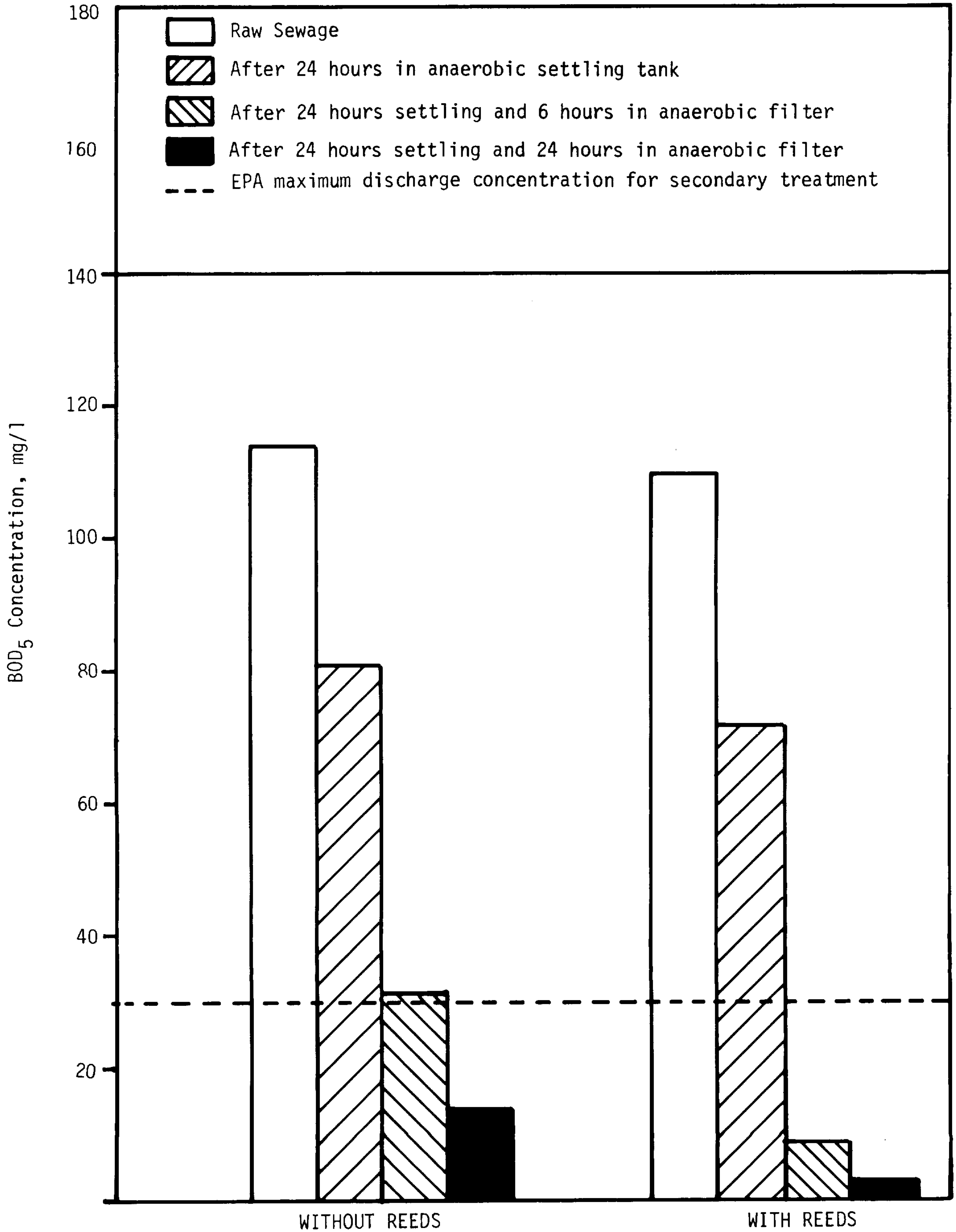

Figure 2. BOD_5 of raw sewage after 24 hours settling and 6 and 24 hours exposure to anaerobic filters with and without reeds.

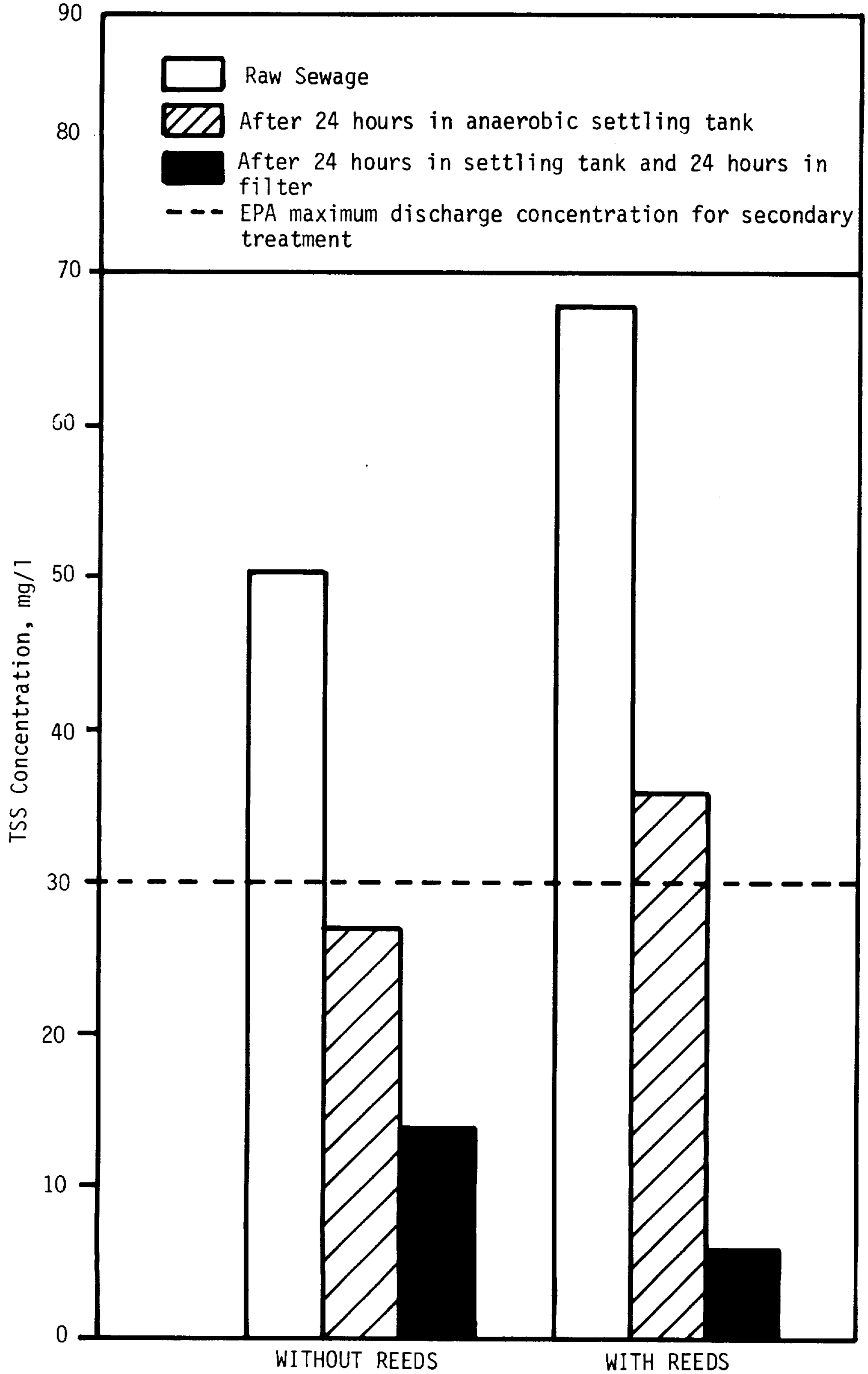

Figure 3. TSS of raw sewage after 24 hours settling and 24 hours in anaerobic filters with and without reeds.

Table 3. Total kjeldahl nitrogen (TKN), ammonia-nitrogen (NH_3-N), and total phosphorus (TP) data for the initial raw sewage and the final effluent after 24 hours in anaerobic settling tanks and 24 hours in rock filters free of reeds (designated as Step 3).

	TKN, mg/l		NH_3-N, mg/l		TP, mg/l	
Exp. #	Initial	Step 3	Initial	Step 3	Initial	Step 3
1.	7.7	7.0	6.9	7.9	8.0	5.6
2.	8.8	8.0	8.8	9.0	5.6	3.9
3.	25.7	21.4	21.4	15.9	3.9	3.8
4.	16.5	16.5	15.9	15.2	6.5	6.5
5.	11.0	11.0	6.5	7.0	3.6	3.6
6.	11.0	11.0	8.2	9.0	4.2	4.2
7.	23.5	23.5	20.0	14.8	5.9	5.9
8.	----	----	12.6	12.0	---	---
9.	11.0	11.0	12.7	12.2	7.2	7.0
10.	23.0	13.2	13.4	12.8	7.0	7.0
Avg.	15.4	13.6	12.6	11.6	5.8	5.3

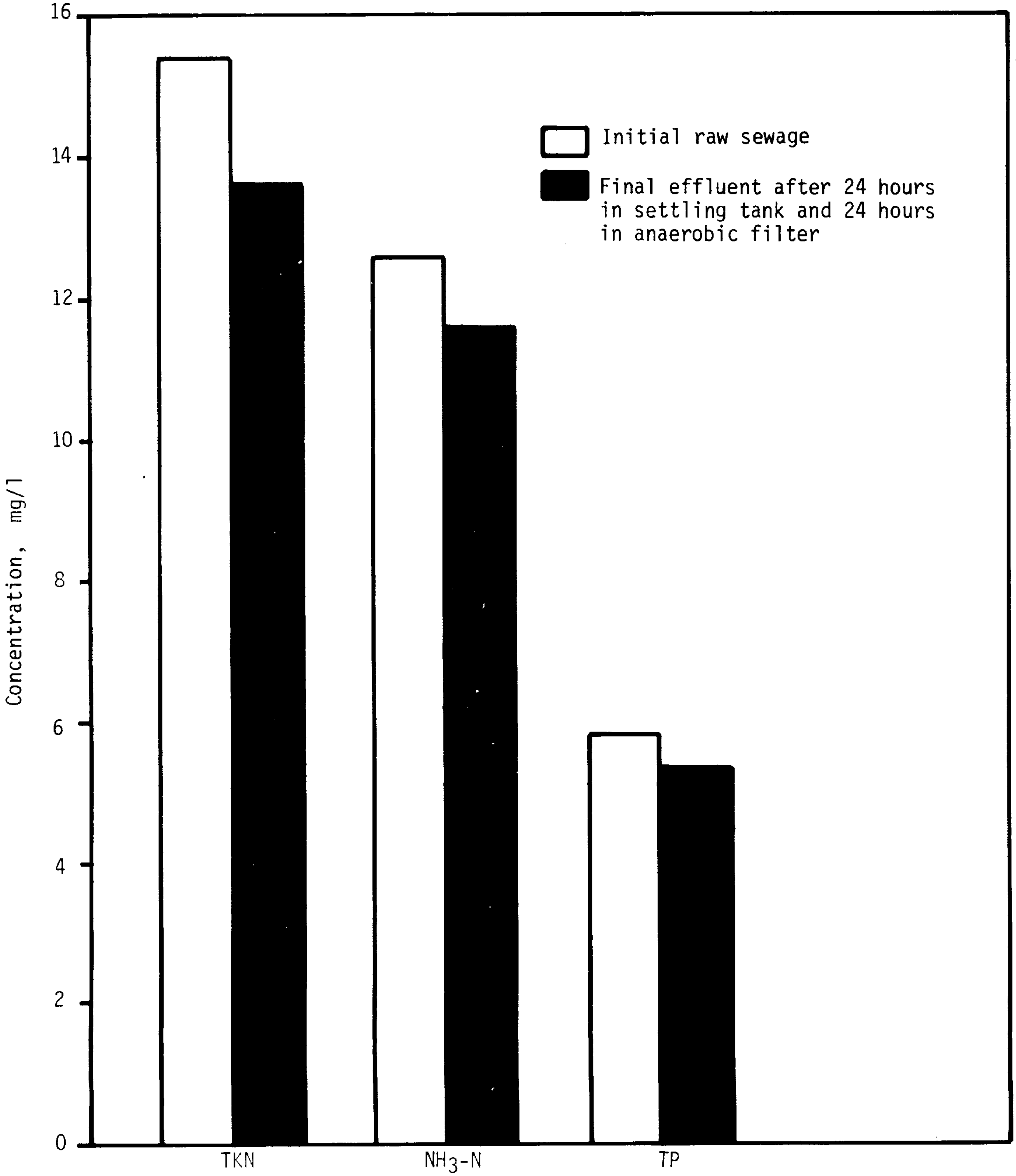

Figure 4. TKN, NH_3-N, and TP of initial raw sewage and the final effluent after 24 hours in anaerobic settling tank and 24 hours in plant-free rock filter.

Table 4. Total kjeldahl nitrogen (TKN), ammonia-nitrogen (NH_3-N), and total phosphorus (TP) data for the initial raw sewage and the final effluent after 24 hours in anaerobic settling and 24 hours in rock-reed filters (designated as Step 3).

	TKN, mg/l		NH_3-N, mg/l		TP, mg/l	
Exp. #	Initial	Step 3	Initial	Step 3	Initial	Step 3
1.	7.4	1.6	20.5	1.6	6.5	1.5
2.	23.7	3.9	---	0.5	2.7	1.4
3.	17.4	4.0	10.8	---	3.5	2.7
4.	8.9	2.6	8.0	0.2	5.4	1.8
5.	17.5	1.7	7.6	0.1	4.5	2.0
6.	16.5	6.5	8.8	1.0	4.1	2.2
7.	23.5	4.5	20.0	1.3	5.9	2.9
8.	16.8	1.2	12.6	0.2	3.0	0.9
9.	12.6	1.1	10.6	0.3	4.4	1.9
10.	16.5	2.2	12.8	0.1	4.0	2.4
Avg.	16.1	2.9	12.4	0.6	4.4	2.0

Figure 5. The data for the hybrid system meets tertiary nutrient standards of 3 mg/l for nitrogen and almost the requirement of 1 mg/l for phosphorus.

The average evaporation loss from the plant-free filter was 6.3 $l/m^2.d$. The evapotranspiration rate for the reed-rock filter was 11.3 $l/m^2.d$.

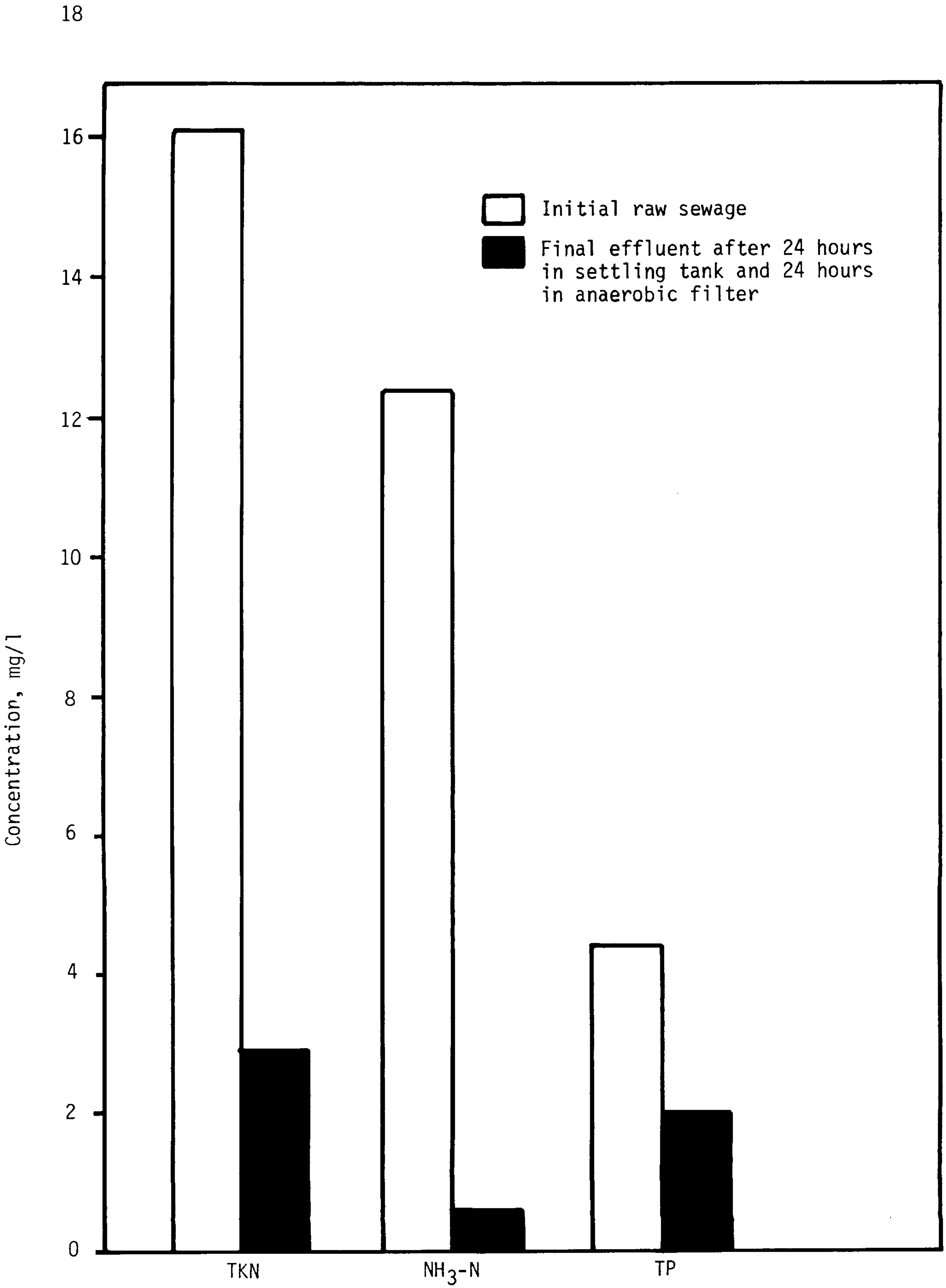

Figure 5. TKN, NH_3-N, and TP of initial raw sewage and the final effluent after 24 hours in anaerobic settling tank and 24 hours in reed-rock filter.

DISCUSSION

The wastewater treatment system discussed in this paper is made up of two major components: component one is a sludge collecting and digesting chamber which may consist of a simple septic tank, a covered anaerobic lagoon or a high surface area anaerobic digester as shown in Figure 6; component two is a hybrid anaerobic filter containing attached microbial filters and vascular aquatic plants. Rocks or vinyl core media can be used for the bottom microbial filter with pea gravel or related material used on top to support the vascular aquatic plants (reeds, etc.). Vinyl core media has been used for 20 years for trickling filter type media and can be obtained commercially. It contains up to 214 square meters of surface area per cubic meter of media. This is approximately four times that of a rock filter. Rocks create a 40-50% void while vinyl core media can create up to a 97% void. Vinyl is also lightweight and easier to transport and install. However, vinyl presently costs more per system than rocks in most parts of the country.

Wastewater from the anaerobic settling tank flows into the bottom of the filter cell then upward to near the top during the treatment process. The lower anaerobic portion of the filter continues the conversion of complex organics which started in the settling tank. The major gaseous end products of anaerobic digestion are carbon dioxide and methane. Complex organics are broken down into simpler compounds which can be assimilated by the reeds. Odorous volatile sulfides produced during anaerobic digestion are either removed by the plants or converted to non-volatile sulfates by aerobic microorganisms near the surface of the filter cell, thus clarifying the final effluent and completing the treatment process.

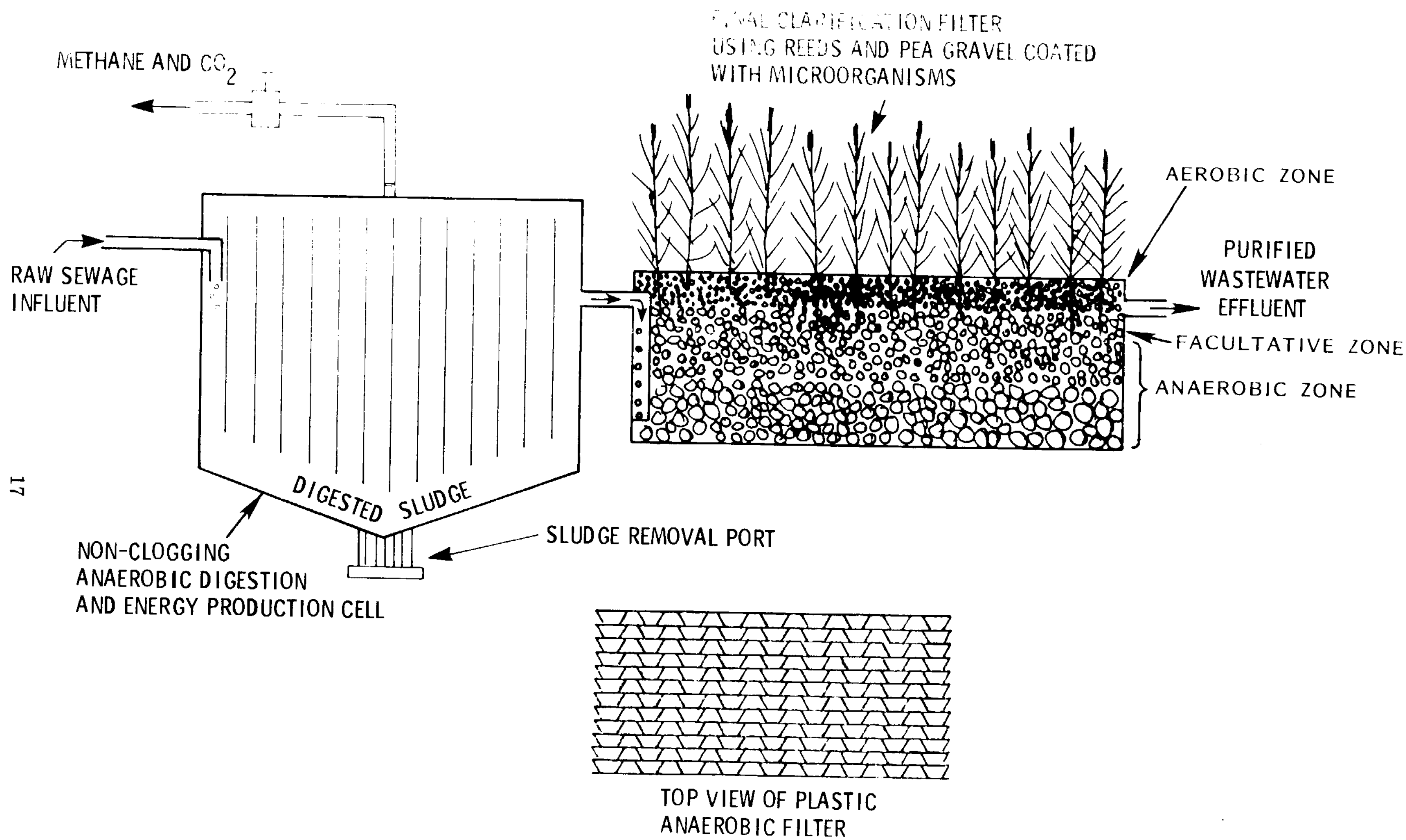

Figure 6. AF-VAP wastewater treatment system.

This system promises to be cost effective in both installation and operation and more versatile than present systems. It can be installed in modules with additional units added in series when required for expansion or advanced wastewater treatment. This concept also has potential as a lightweight, compact system for wastewater treatment in space stations.

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